1999-01-5507

Designing Procedures for Controller-Pilot Data Link Communication: Effects of Textual Data Link on Information Transfer

Margaret-Anne Mackintosh
San Jose State University/NASA Ames Research Center

Sandra Lozito
NASA Ames Research Center

Alison McGann and Elizabeth Logsdon
San Jose State University/ NASA Ames Research Center

1999 World Aviation Conference
October 19-21, 1999
San Francisco, CA

SAE International
400 Commonwealth Drive
Warrendale, PA 15096-0001 U.S.A.

American Institute of Aeronautics and Astronautics
370 L'Enfant Promenade, S.W.
Washington, D.C. 20024

Published by the American Institute of Aeronautics and Astronautics (AIAA) at 1801 Alexander Bell Drive, Suite 500, Reston, VA 22091 U.S.A., and the Society of Automotive Engineers (SAE) at 400 Commonwealth Drive, Warrendale, PA 15096 U.S.A.

Produced in the U.S.A. Non-U.S. purchasers are responsible for payment of any taxes required by their governments.

ISSN #0148-7191

All AIAA papers are abstracted and indexed in International Aerospace Abstracts and Aerospace Database.

All SAE papers, standards and selected books are abstracted and indexed in the Global Mobility Database.

Copies of this paper may be purchased from:

AIAA's document delivery service
Aeroplus Dispatch
1722 Gilbreth Road
Burlingame, California 94010-1305
Phone: (800) 662-2376 or (415) 259-6011
Fax: (415) 259-6047

or from:

SAExpress Global Document Service
c/o SAE Customer Sales and Satisfaction
400 Commonwealth Drive
Warrendale, PA 15096
Phone: (724) 776-4970
Fax: (724) 776-0790

SAE routinely stocks printed papers for a period of three years following date of publication. Quantity reprint rates are available.

1999-01-5507

Designing Procedures for Controller-Pilot Data Link Communication: Effects of Textual Data Link on Information Transfer

Margaret-Anne Mackintosh
San Jose State University/NASA Ames Research Center

Sandra Lozito
NASA Ames Research Center

Alison McGann and Elizabeth Logsdon
San Jose State University/ NASA Ames Research Center

ABSTRACT

This research focused on identifying communication strategies and procedures related to efficient and error-resistant data link communication. A coding scheme was developed that identified five steps in the data link communication cycle in which information may need to be transmitted between operators. This methodology was applied to a data link full mission study with 10 flight crews as participants. Initial results indicated that the amount of information transferred may impact communication timing and efficiency. The impact of data link upon the roles and procedures of the crewmembers is discussed.

INTRODUCTION

The aviation system requires much data transmission among a variety of users and participants. The flight crew's task of getting an aircraft safely from one place to another requires cooperation between the crewmembers. Shared information is often critical for safety of flight. Ideally, all information of this type is shared and known to all crewmembers [1]. Evidence suggests that as information is shared and processed by other crewmembers, it facilitates more error-checking behavior, possibly on the part of the speaker and the listener. For example, Foushee and Manos [2] found that within-cockpit communication patterns were related to crew performance. Specifically, they found that when more information was transferred between crewmembers, there were fewer crew operational errors. In an analysis of National Transportation Safety Board reports in which aviation accidents and incidents were discussed, Orasanu, Dismukes, and Fisher [3] discovered that useful instrument information was often not communicated between crewmembers.

In order to move aircraft from departure to destination points, data about the system and the components within it are passed among air traffic controllers, pilots, airline companies, and passengers. Clearance information is one part of the necessary transfer. There are data transmission and confirmation processes that occur each time an ATC clearance is sent to an aircraft.

The information transfer process that occurs when handling an ATC clearance involves many communication and procedural tasks that must be conducted in a timely manner. There are several opportunities for human error in that process. Many reports have uncovered difficulties during clearance delivery and reply in today's voice environment [4, 5]. Some procedures conducted by flight crewmembers may affect the risk of error during these transactions. When the crew receives clearance data on the flight deck, they must ensure that they comprehend the instruction, and that they can comply with it. It is critical for all the crewmembers to receive the same data within the clearance, and that their understanding about the meaning of the clearance be uniform. In order to guarantee this, the information must be distributed among the crew in a thorough and efficient manner. Information relevant to the safe maneuvering of the aircraft should be provided to all the crewmembers and represented in the aircraft systems accurately. Previous research emphasizes the importance of timely and thorough distribution of information [2, 3, 6].

In addition to interactions among the human agents, crews must also interact with the aircraft's systems and subsystems. Once the clearance data are deemed acceptable, crews must enter any required parameter changes into the appropriate system or device. There can be more than one modification required within a single clearance. For example, it is common that speed and altitude may both need to be changed to comply with a clearance. The pilots then monitor the aircraft to ensure that the aircraft behaves as expected.

The construct of information distribution in aviation has been discussed in previous work by Hutchins [7]. In describing the procedures associated with speed modifications on the flight deck, Hutchins considers the flight deck as an entire system. The system is involved in assisting in the memory of aircraft speed through displays, input devices, and crew procedures. These functions help to disseminate the information to crewmembers and to the aircraft subsystems, providing various error checks throughout this migration. In addition, the crewmembers are able to match their internal representations of speed to the external representations of speed [7].

Problems with voice communications that arise from frequency congestion and verbal miscommunications have led the aviation industry to consider data link communications for air-ground information transfer. As data link communication becomes more prevalent in the aviation system, some of the activities and procedures related to information transfer will be modified. The near-term use of data link will be represented primarily by textual information provided to controllers and pilots. In addition, data link may be presented on a display that is time-shared. Thus, the information may not be readily available at all times to all the users. Issues associated with modality and interface design, such as visibility of text and alerting strategies, become significant considerations when transmitting clearance information using data link technology.

The crew procedures and tasks required to handle a data link message on the flight deck indicate some interesting differences between the voice modality and the data link modality. The necessary involvement with the data link interface when creating, transmitting, receiving, and responding to an ATC clearance may create some shifts in information processing procedures. One advantage of the voice environment is its accessibility. When there are multiple operators on the flight deck, and voice is used to transmit information over the radio frequency, then all the operators at the workstation that are plugged into that frequency have an opportunity to hear the transmission. Thus, the information is generally available to the operators for whom the information is most relevant. With a visual data link that is textual in nature, the information for a clearance will likely be more centralized in its location, and therefore may become less available to multiple operators on the flight deck.

Previous research on textual data link has found both timing and procedural differences for flight crews using data link to handle ATC clearances compared to crews using voice (see [8] for a review of data link research, [9, 10, 11]). Although there are data link interface issues associated with lengthened data link acknowledgment times when compared to voice (e.g., number of data link interface steps required for message display or response), it is unclear what other procedures may be contributing to the longer data link response times.

This paper attempts to investigate the potential changes to the accessibility of clearance data that may arise from the use of textual data link on the flight deck. The communication steps within a typical clearance process are identified, the exchange of information at those steps is determined, and the potential consequences of the success or failure of information exchange upon flight deck timing and communication events are examined.

METHOD

DATA LINK SIMULATION STUDY – Participants were ten flight crews from one US carrier, each consisting of a captain and a first officer who flew an advanced transport aircraft (e.g. 737-300, 757/767). Crews flew the Advanced Concepts Flight Simulator (ACFS) located in the Crew Vehicle System Research Facility at NASA Ames Research Center. The ACFS is a generic, full-motion transport aircraft simulator representative of a "glass cockpit" aircraft, with a Flight Management System (FMS) similar to that of a Boeing 757/767 aircraft (see [12] for a complete description of the simulator and research facility). Five crews flew experimental scenarios in which data link was used as the primary ATC communication medium and five crews flew the same scenarios using standard voice communication procedures [9].

Data Link Interface and Functionality – The interface for data link communication used in this study was through the two Multipurpose Control Display Units (MCDUs) and was time-shared with the Flight Management Computer (FMC). Messages could be viewed on either of the MCDU displays (see Figure 1 for data link interface).

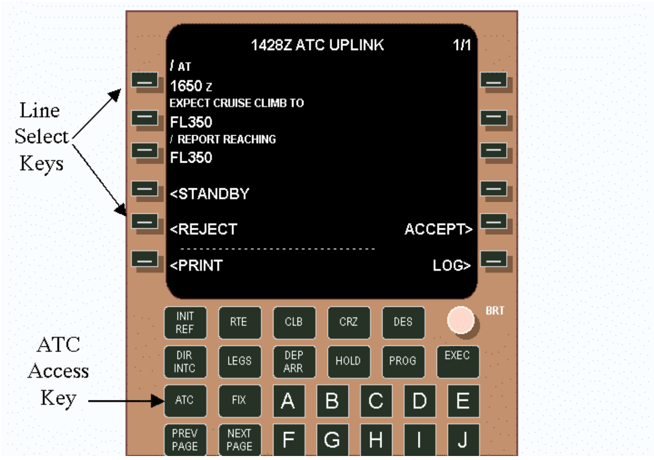

Figure 1. Time-shared data link implementation interfaced through the MCDU

Several discrete steps were required to handle a data link clearance. Upon receipt of a data link message on the flight deck, a visual alert was displayed on the upper Engine Indicating Crew Alerting System (EICAS) display indicating the presence of a message in the queue (Alert step). This was accompanied by a single selcal chime. The visual alert disappeared once the message was acknowledged by either flight crewmember. Each message page consisted of a subtitle, a time stamp representing the time the message was sent from the controller's data link system, and a page number over the total number of pages available for that message.

Next, crews could access the message via an ATC function key, which was available as a hard key on the MCDU keyboard (Access step). Message content then had to be read aloud by one of the crewmembers (Read Aloud step), and may have been repeated back by the other crewmember to ensure correct understanding (Read Back step).

Finally, crewmembers used the MCDU to send an electronic response to the controller (Acknowledgement step). The choices for message acknowledgment were displayed at the bottom of the message. The acknowledgments differed and were dependent upon the type of message, but included responses such as "accept", "reject", and "standby". For a limited number of clearances, there was also a "load" prompt, which allowed crews to autoload clearance information into some aircraft subsystems.

<u>Data Link Training and Procedures</u> – The message alerting, display, and response techniques were explained and demonstrated in detail. Also, the ability to directly enter clearance information into the FMC (where appropriate), as well as the ability to review and downlink data link messages, were demonstrated and practiced. In addition to exposure to the interface, the data link training also included explicit instructions on crew procedures for data link communications. Specifically, the Pilot-Not-Flying (PNF) was instructed to read aloud the data link message to the Pilot-Flying (PF) prior to the decision to accept or reject the message.

INFORMATION VULNERABILITY POINT CODING SCHEME – In the current work, five information vulnerability points were identified for this time-shared implementation of data link: Alert, Access, Read Aloud, Read Back, and Acknowledgment. These points were defined as discrete steps in the data link communication cycle, and it was hypothesized that information about either content or action needed to be transferred at each step to maintain a mutual understanding of the communication process.

A team of three raters used consensus coding to obtain a score at each of the five vulnerability points for each message sent to the five data link crews. Ratings were made from video tapes, which included over-the-shoulder views of both pilots interacting with the flight deck instruments and displays. Vulnerability point scores were made using a three level scale to estimate information transfer. Levels of this scale were as follows: complete information transfer, partial information transfer, and no information transfer. These broad categories were operationally defined for each vulnerability point.

The Alert vulnerability point was coded at the time that a new data link message arrived on the flight deck. Raters coded any verbalizations related to the receipt of a new message, though crews had not been instructed to "think aloud" while handling data link. The three levels of the information transfer scale were defined as:

- Complete: Verbalization of a new message present;
- Partial: Ambiguous utterance at the time of message receipt;
- None: No comment about new message.

The Access vulnerability point was coded at the time one of the crew members used the MCDU to access the data link message. Level of the information transfer scale were:

- Complete: Verbalization of intent to access message;
- Partial: Ambiguous comment at time of access;
- None: No comment about accessing message made.

The Read Aloud vulnerability point represented the amount of the content of the message that was read aloud by the crewmember handling the data link communications (generally the PNF). This point is similar to the controller's issuance of the clearance in the voice environment. The three coding levels were defined as follows:

- Complete: All elements of the message and the values, metrics, and indication of direction were read aloud;
- Partial: Either one or more elements of the message were not read aloud or all elements were read, but missing values, metrics or indication of direction on one or more elements;
- None: No message content read aloud.

The Read Back vulnerability point represented the amount of message content that was repeated back to the PNF by the PF. This repetition is proposed to be similar to the PNF's read back of message information to the controller in the voice environment. Both read backs serve as error checking measures to assure that the clearance information was successfully transferred. Levels of the coding scale were:

- Complete: All elements of the message were repeated including all values and metrics;
- Partial: Either one or more elements of the message was dropped or all elements were repeated, but a value or metric was not given.

- None: Either no information was repeated or an acknowledgment that contained no information about message content was given (e.g. "Okay, got it").

The Acknowledgment vulnerability point represented the amount of information transferred between crewmembers when the response was sent to the controller via the MCDU or via the voice channel. The levels of the information transfer were:

- Complete: Verbalization of type of acknowledgment sent to ATC;
- Partial: Utterance without specifying whether accepting or rejecting the message contents;
- None: No verbalization at the time of message acknowledgment.

In addition to the vulnerability points scores, other behaviors were coded from the video tapes, including clarifications about messages or actions taken on message content, errors made in reading and/or handling data link messages, and other crew duties which distracted crews from handling data link messages. These variables were included in order to assess the impact of data link communications on flight crews' present procedures. Finally, timing data related to the reading and implementation of clearances also were collected.

RESULTS

A total of 171 messages were sent to the five data link crews. The mean acknowledgment time (number of seconds from message receipt to acknowledgment) for 155 messages that were acknowledged was 27.5 s with a SD of 38.7 s. Acknowledgment time may or may not have included the input time, depending upon the crews' message handling strategy (i.e. whether they chose to input prior to acknowledgement or the reverse). Time to finish handling the message, including inputting all message elements, averaged 28.6 s with a SD of 38.8 s. The five voice crews had a mean message acknowledgment time of 7.9 s. Because the current work focused on data link communication, voice crews will only be discussed as a reference group to the data link crews. For more information on the performance of crews in the voice condition, please see [9].

Figure 2 shows the estimated amount of information transferred for data link messages at each information vulnerability point. More information appears to have been passed at data link vulnerability points that have similar procedures in the voice environment (e.g. Read Aloud, Read Back and Acknowledgment). Specifically, at least 50% of the messages had at least partial information transfer or higher for the three data link vulnerability points that have analogous steps in the voice environment. In contrast, the steps in the communication process that were novel in data link (e.g. Alert and Access) were not accompanied by much verbalization. More than 70% of the messages at both the Alert and Access vulnerability points had no information transferred. While the acknowledgment procedure is different in the data link environment (a physical button press) compared to the voice environment (completing the read back), the crews still tended to provide more information for the Acknowledgment point than for the novel Alert and Access steps.

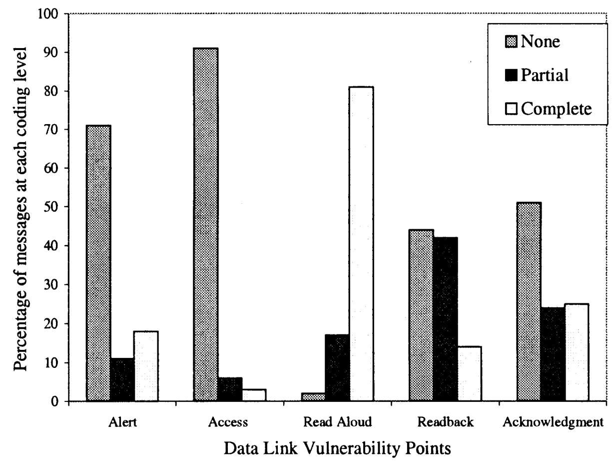

Figure 2. Percentages of messages for each vulnerability point and level of information transfer.

The following sections investigate the relationship between the amount of information transferred at each vulnerability point and other performance measures.

ALERT VULNERABILITY POINT – The information transferred at the Alert vulnerability point served as the first indication by a crewmember that a new data link message had arrived on the flight deck. The relationships between the amount crews articulated about the presence of a new message and other variables, such as message access timing and task scheduling, were investigated.

Time to access a message – The average time it took crews to access a new data link clearance was 5.9 s (SD = 5.1 s), with access time being defined as the number of seconds from receipt of the message (crew received aural and visual alerts) to the time that it was accessed through the MCDU. To assess the relationship between Alert vulnerability score and access time, a Spearman's correlation coefficient was calculated ($\underline{r}_S$ = .13, $\underline{p}$ = .08), indicating that access time was not correlated with verbalizations at the Alert vulnerability point.

Distractions – The number of distractions that occurred prior to the access of data link messages was investigated. Distractions were defined as any task not related to the new data link message, which the crew performed between the message receipt and message acknowledgment, that delayed the crew's handling of the data link message. A distraction also was recorded if a crew did not access the data link message within 8 s of receiving it and were not engaged in any other tasks. This allowed for the identification of distractions that may be influenced by other factors, such as missed alerts and crews' involvement in other tasks.

Twenty-eight of the 171 (16.4%) data link messages contained distractions that occurred prior to accessing the message. Spearman's correlation coefficient was calculated for occurrence of distractions before access and message access time ($\underline{r}_s$ = .63, $\underline{p}$ < .001). This indicated that messages with distractions before message access tended to have significantly longer access times than messages without distractions. The mean access time for messages with distractions was 14.8 s (SD = 7.3 s), while it was 4.2 s (SD = 1.5 s) for messages without distractions. There were no specific behaviors that consistently diverted the crews' attention from handling data link messages. Crews often finished their current task before handling the data link message (e.g. inputting values into flight systems, handling previous clearances or finishing a checklist).

Table 1 shows the distribution of the two types of distractions by the three levels of information transfer. It is interesting to note that all of the messages which had a message access time of 8 s or greater also had no verbalization by either crew member about the presence of that message.

Table 1. Frequency of distraction types by levels of Alert Vulnerability scores

	None	Partial	Complete
Distraction by other task	11	2	9
Greater than 8 s access time	6	0	0

ACCESS VULNERABILITY POINT – Information transfer at the Access Vulnerability point was considered important as it conveyed to the other crewmember why the PNF was interacting with the MCDU. Since the implementation of data link under study was time-shared with the FMC, the PNF's use of the device could be ambiguous. We found few verbalizations about the PNF's intention to access data link messages. In 91% of the messages, no utterances was made while accessing the message. In 6% of the messages an ambiguous comment was made, and in only 3% of the messages a clear intention to assess the new message was stated. Because of the concentration of responses in the no information transfer category, no additional analyses were conducted.

READ ALOUD VULNERABILITY POINT – The Read Aloud vulnerability point represented the first time that the information was distributed among the crew members as the PNF read the content of the message aloud. In addition to coding the amount of information transferred at PNF's read aloud for data link messages, the amount of information transferred at the PNF's read back for the crews that flew in the voice environment also was measured using the same scale coding categories. This allowed for the investigation of how the PNF's role in handling the communication changed between environments. Specifically, we assessed the relationship between communication modality and amount of information transfer on clarifications and errors. Finally, the effect of the amount of information transfer and message timing was assessed.

Clarifications – Clarifications were defined as questions concerning the content of the message. To assess the impact of different communication modalities (voice and data link) on clarifications, messages with information content clarifications were compared across the levels of information transfer scale. Because very few messages fell into the no information transfer category, only two levels of the scale were used: complete information transfer and partial information transfer.

Figure 3 depicts the estimation of the amount of information transferred in the voice and data link communication modalities. It can be seen that for clearances in which all message elements were read aloud, voice and data link had similar percentages of messages with clarifications. When only partial clearance information was read aloud, the percentage of messages with clarifications in the voice condition is similar to that of complete information transfer. However, for data link clearances with partial information transfer the clarification rate was 3.5 times that of voice communication. These data suggest that data link messages in which only part of the message was read aloud were more likely to lead to confusion compared to data link messages fully read aloud or for voice messages in general. Although these differences appear significant, these data must be interpreted cautiously. Because of the small sample size and methodology used, inferential statistics could not be applied to these data.

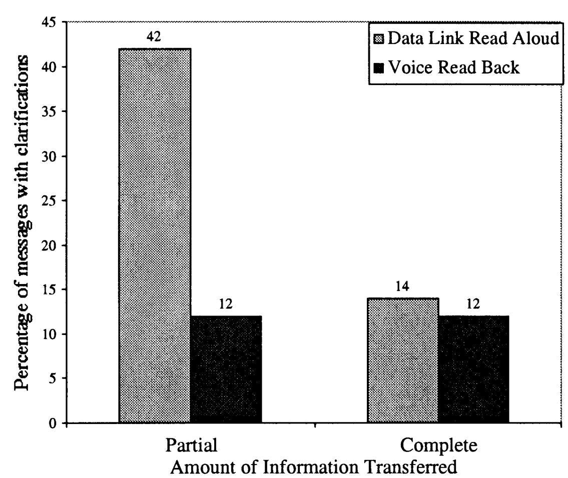

Figure 3. Percentage of messages with clarifications by estimated level of information transfer and the communication modality.

Errors – The number and types of errors also were coded from the video tapes. Errors were defined as any statement (not an inquiry) containing erroneous information regarding a clearance. All errors in this study consisted of crews misreading a clearance element. For example, one pilot said "descend to FL270" instead of "maintain FL270". However, in no case did crews enter erroneous information into the aircraft systems.

Figure 4 shows the percentage of clearances with errors as a function of the communication modality and amount of information transferred. Consistent with the clarification data, the percentage of messages with errors in the voice condition is similar regardless of how much of the information was read back by the PNF. For data link messages, however, the amount of information read aloud does appear to be related to the errors in communication. Specifically, when the entire clearance was read aloud the error rate appears to be similar to that of voice communication. However, when only parts of the message were read, the error rate increased sharply. Again, these data should be interpreted cautionsly, because due to the small sample size and methodology used, inferential statistics were not applied.

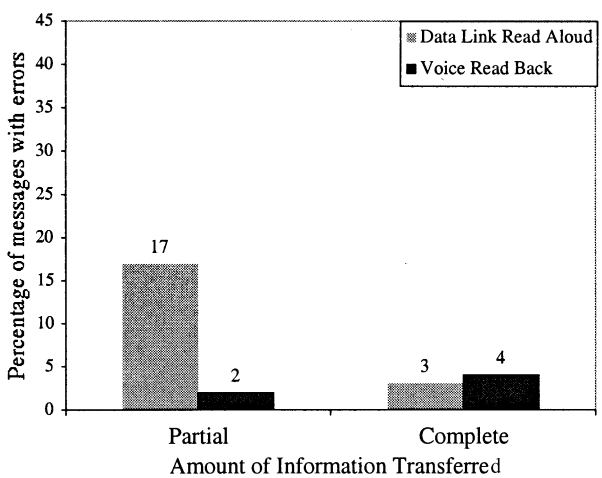

Figure 4. Percentage of messages with errors by amount of information transferred and communication modality.

Message processing time and Read Aloud – Message processing time was a measure of how long it took crews to read, implement, and acknowledge the content of a data link clearance, including any additional time needed for clarifications. Message processing time was defined as the number of seconds starting from when the PNF accessed the message to the acknowledgment or loading of the last element, whichever was longer. This allowed for the investigation of how the amount of information passed between crewmembers affected how long it took the crew to cognitively and physically work through the entire message handling procedure. Message processing time was found to be negatively correlated with the Read Aloud vulnerability point controlling for the number of elements in the message (partial correlation = -.15, p = .03). Message processing time for the 2 messages with no information transfer averaged 75.0 s (SD = 65.1 s); the 27 messages with partial information transfer averaged 32.2 s (SD = 46.5 s); and the 125 message with complete information transfer averaged 20.0 s (SD = 34.0 s).

READ BACK VULNERABILITY POINT – Information transfer at the Read Back vulnerability point was considered as an important form of error-checking on the flight deck. More information repeated back by the PF allowed for both crewmembers to check their understanding of the message contents. This process is hypothesized to be analogous to the PNF's required read back of the clearance to the controller in the voice environment. This study found that only 56% of the clearances had some read back of the message content by the PF. Only in 14% of the messages did the PF read back the entire message, while 42% had at least one of the messages elements repeated. In the remaining 44% of the messages, no part of the message content was repeated.

ACKNOWLEDGMENT VULNERABILITY POINT – The Acknowledgment vulnerability point represented the amount of information transferred when a crewmember was sent either an accept or reject response to ATC. Information sharing at this point is critical to shared awareness due to the time-sharing of the data link MCDU operations with the FMC functionality in this study. It is also important that all crewmembers be aware of the presence and nature of the acknowledgment to the ground user.

Distractions – In order to assess the impact of crews performing other tasks while handling a data link message, the relationship between distractions that occurred before the acknowledgment and message acknowledgment times was assessed. There were 26 messages with 27 distractions that occurred after access and read aloud of the message, but before the acknowledgment. Of the 26 messages with distractions, crews acknowledged 13 of them after performing other tasks, and the remaining 13 were not acknowledged. For messages that were acknowledged by the flight crews, a significant Spearman's correlation was found between message acknowledgment time and messages with or without a distraction (r_s = .46, p < .001). The average message acknowledgment time for messages with a distraction was 112.4 s (SD = 76.1), while mean acknowledgment time for messages without distractions was 19.2 s (SD = 17.4 s).

CONCLUSION

Previous research has shown that textual implementation of data link used for ATC clearances lengthens the acknowledgment times compared to voice [8, 11] as well as changing crew procedures for handling clearance information [10]. The present research hypothesized that these differences in communication timing and procedures may be partially due to a change in the accessibility and distribution of message content on the flight deck when switching from the current voice ATC environment to a textual based data link system. Results from this study indicated that when the PNF verbalized less of the total message content, both the time required for crews to complete a message transaction and the need for later message clarifications increased. Distractions to the data link handling process also had significant timing impacts, especially when the distractions occurred after the message had been accessed.

The proposed information vulnerability points allowed for the investigation of information transfer at the individual steps in the data link communication process. The data presented suggest that the amount of information transferred at certain points can affect data processing time. The Read Aloud vulnerability point was associated with the greatest amount of information transfer. Message processing time lengthened when less of the message content was read aloud. This is probably related to the concurrent finding that there were more clarifications about the content of a clearance when only part of the message was read aloud compared to messages in which all message information was verbalized.

While amount of information transferred at the Read Aloud did have an effect on communication timing and processing of the message, information transfer had a less direct effect on timing at the Alert vulnerability point. Message access time was not greatly affected by the verbalization of the presence of a new message. However, it is interesting to note that for all the clearances that had both a distraction that was prior to the access of the message and that was unrelated to handling another task, no verbalizations were made at the Alert vulnerability point. While verbalizations about the receipt of a new message do not add a significant amount of additional processing time to messages, they may serve as a secondary alerting mechanism for those instances when a crewmember might not have perceived either the aural or visual alerts. Verbalizations at the alert also could serve as a means to clarify an ambiguous aural alert, as in cases in which the same aural alert is used for multiple systems (data link communications, flight attendant calls, etc.).

Two of the proposed benefits of data link have been the permanent storage of message content and the resulting greater flexibility for crews to schedule their tasks. Previous research has shown that crews more often perform other tasks while handling data link clearances than in a voice environment [8, 9, 10]. The present analyses showed that these distractions from the communication task at various points in the data link communication cycle could have a large impact on message timing. Distractions prior to access added about 10 s to the average message access time, though in all cases the crew went on to access and read the data link clearance. With the upcoming introduction of data link communication in the domestic en route environment, the need for timely response to ATC clearances has been highlighted. An additional 10 s delay prior to the pilot's handling of a message may be critical. The controller will likely have a timer function (sometimes called the "shot clock"), which will signify that the controller needs to take some action to determine the status of the message or to close the message, should time expire. It has been suggested that the "shot clock" for the controller should be set at 40 s for the enroute environment. Ten seconds additional time seems significant when considering a time parameter of 40 s for message acknowledgment, particularly since these timing data do not include transmission times for message delivery.

Distractions after message access, however, had a much larger impact on message acknowledgment times, increasing them an average of 93 s. Handling of other tasks after access of the data link message also seemed to be problematic procedurally. Half of the messages with distractions were not acknowledged by the flight crews at all, and the remaining messages had acknowledgment times almost three times the length of the proposed 40-second controller "shot clock." If flight crews are likely to interrupt handling a data link message, additional procedures or alerting mechanisms need to be investigated as a means to bring the crews back to the data link task. While the visual alert remained on the upper EICAS display until all data link messages were acknowledged, perhaps the visual alert was not distinct enough to call the crew's attention to an open transaction. An enhanced visual alert or a flight crew "shot clock" should be considered.

The shift to processing messages in the visual modality from the auditory channel may lead to increased competition for visual attention between accessing ATC information content and the already visually laden flight deck environment. Moreover, this modality shift in the presentation of clearance information appears to fundamentally change the role of the PNF in the communication cycle. The PNF becomes the primary distributor of ATC content message in a data link system compared to acknowledging and verifying information transfer in the present voice system. Results from this paper suggest that the amount of message content the PNF makes available within the flight deck can affect both the overall understanding and timing of the message.

The methodology for assessing information transfer proposed and described in this paper allows for a more thorough investigation of the timing and procedural impact of data link communication. Further work will be done to assess the impact of information transfer at the vulnerability points not addressed in this paper. In addition, future research needs to be conducted to validate the procedures and changes suggested from this methodology.

ACKNOWLEDGMENTS

This work was funded by NASA Ames Research Center's Aviation System Operations Program.

REFERENCES

1. Orasanu, J. (1993). Decision making in the cockpit. In E. Weiner, B. Kanki, & R. Helmreich (Eds.). Cockpit resource management (pp. 137-172). San Diego: Academic Press.
2. Foushee, H. C. & Manos, K. L. (1981). Information transfer within the cockpit. In C. Billings and E. Cheaney (Eds.), Information transfer problems in the aviation system. NASA TP-1875. Moffett Field: NASA Ames Research Center.
3. Orasanu, J., Dismukes, R. K., & Fisher, U. (1993). Decision errors in the cockpit. In Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting (pp. 363-367). Santa Monica, CA: Human Factors Society and Ergonomics Society.
4. Billings, C. & Cheaney, E. (1981). Information transfer problems in the aviation system. NASA TP-1875. Moffett Field: NASA Ames Research Center.
5. Lee, A. & Lozito, S. (1989). Air-ground information transfer in the national airspace system. In R. Jensen (Ed.), Proceedings of the Fifth Symposium on Aviation Psychology (pp. 425-432). Columbus, OH: The Ohio State University.
6. Orasanu, J. (1991). Individual differences in airline captains' personalities, communication strategies, and crew performance. In Proceedings of the Human Factors Society 35th Annual Meeting (p. 991-995). Santa Monica, CA: Human Factors and Ergonomics Society.
7. Hutchins, E. (1995). How the cockpit remembers its speed. Cognitive Science, 19, 265-288.
8. Kerns, K. (1991). Data link communications between controllers and pilots. International Journal of Aviation Psychology, 1, 181-204.
9. Logsdon, E., Infield, S., Lozito, S., Mackintosh, M., McGann, A., & Possolo, A. (1995). Cockpit data link technology and flight crew communication procedures. In R. S. Jensen (Ed.) Proceedings of the Eighth Symposium on Aviation Psychology, (pp. 324-329). Columbus, OH: The Ohio State University.
10. Lozito, S., McGann, A., & Corker, K. (1991). Data link air traffic control and flight deck environments. In R Jensen (Ed.), Proceedings of the Sixth Symposium on Aviation Psychology (pp. 1009-1015). Columbus: The Ohio State University.
11. McGann, A., Morrow, D., Rodvold, M., & Mackintosh, M. (1998). Mixed-media communication on the flight deck. International Journal of Aviation Psychology, 8(2), 137-156.
12. Shiner, R. & Sullivan, B. (1992). Man-Vehicle Systems Research Facility: Design and Operating Characteristics. Paper presented at AIAA/AHS Flight Simulation Conference, Hilton Head, SC.

CONTACT

The principle authors can be contacted via e-mail at NASA Ames Research Center: Sandy Lozito 'slozito@mail.arc.nasa.gov' or Margaret-Anne Mackintosh 'mmackintosh@mail.arc.nasa.gov'. For additional information on Human Factors research being conducted at NASA Ames Research Center, please see the Human Factors Research and Technology Division's homepage at http://human-factors.arc.nasa.gov.